2016

Eons, Eras and Periods

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Introduction

Because we will occasionally use the names of eons, eras, periods, and epochs of time in the following discussions, we have included a time chart for your information that include the eons, eras, and periods referred to in our discussion (Figure 01).

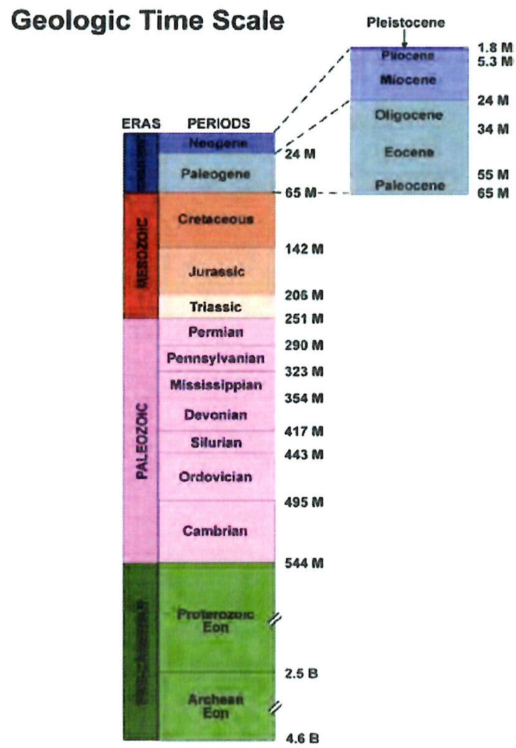

Figure 01. Table of Eons, Eras, Periods, and Epochs.

Appearance of Earth: We all know what Earth looks like today. We have globes that show it in 3D and maps that portray it in 2D and, of course, we now have satellites that allow us to view its surface in extreme detail. But what do you think it looked like in the beginning when the continents and oceans had just formed? Once formed, did Earth's surface remain the same or did it change over time? Where did all the water come from to create the oceans? We are, in fact, the only planet in the Solar System that has so much water. Was there an early atmosphere and what was its composition? When did life appear? To answer these questions, let's go back to the very beginning when planet Earth was being formed from protoplanet Earth.

Protoplanet Earth: Protoplanet Earth was simply a homogenous sphere of elements, minerals, and rock that grew over time as planetesimals consisting of asteroids, meteoroids, and comets that formed from cosmic debris were attracted by gravity to the center of an eddy that orbited the newly-formed star, our Sun (Figure 02). Once a certain mass of cosmic debris had accumulated, an increasing force of gravity molded it into a sphere much like you would mold a mass of snow into a snow ball (Figure 03). Over time, some of the gravitational energy was converted into heat. As to how the heat is generated; as the planetesimals impact the surface of the protoplanet and later of Earth, the friction of impact caused the kinetic energy stored within the planetesimal to be released in the form of heat. When the temperature of the interior of the protoplanet reached a few thousand degrees Celsius,

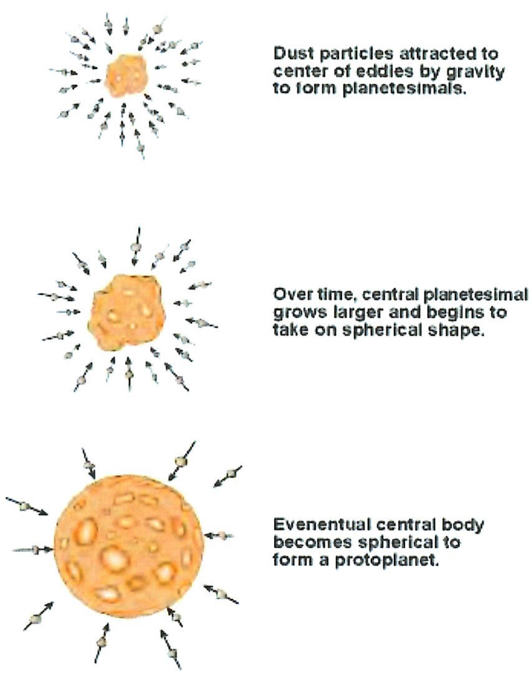

Figure 02. Growth of a protoplanet.

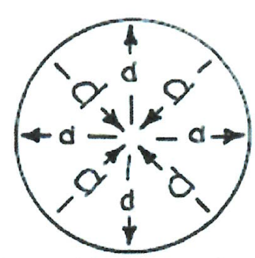

Figure 03. Separation of protoplanet based on density.

the protoplanet began to melt, Some scientists believe that the protoplanet was once a completely molten sphere of magma while others picture the protoplanet at this time to be a mixture of magma and rock particles made as the magma solidified. Magma is molten rock located below Earth's surface.

About 4.6B years ago, the materials within the protoplanet began to separate based on density; density is the mass of a material per unit volume (Figure 03). The densest material of all, molten iron, settled to the center to form Earth's core that is about 4,000 miles in diameter with a density of 15. As a point of interest, we might point out that while hydrogen is the most abundant element in the Universe; iron is the most abundant metal in the Universe. Once the core formed, it began to be surrounded by layers of molten rock, decreasing in density outward. The layer immediately above the core eventually cooled and solidified to form a layer 1,742 miles thick called the mantle consisting of an iron-rich rock called peridotite; not as iron rich as the core, but with sufficient iron to give it a density of about 6. Lastly, the outermost layer called the crust formed (Figure 04). The crust is the thinnest component of Earth, and consists of two components, a layer of basalt ranging from 3 to 6 miles thick with a density of about 3.1 that eventually formed the ocean bottom and the continental crust that was composed of granite surrounded by oceanic crust. The granitic crust essentially consisted of granitic islands of various sizes and shapes that ranged in thickness from 20 to 30 miles with a density of 2.9. Because of the lower density of the crust, it literally floats on the surface of the mantle with the mantle floating on the molten core like an ice cube floats on water. Most of our discussion will center on the crust simply because that's where we live.

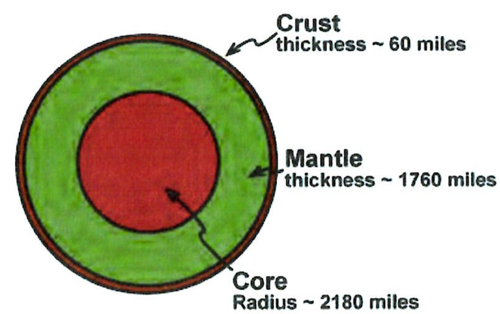

Figure 04. Drawing showing core, mantle, and crust of Earth.

The Lithosphere: An important aspect of Earth's structure is that the combined crust and outermost portion of the mantle are brittle, meaning that if subjected to forces, they will break. The combination of the crust and the brittle portion of the mantle is called the lithosphere. Below the lithosphere, there exists a layer ranging from 50 to 120 miles thick called the asthenosphere (Figure 05). What is important about the asthenosphere is that it is plastic. Before we go on, we must explain what plastic means. To a geologist, it does not mean what you think it means. In our modern vernacular, the term plastic has been used to describe a material that is used to make familiar objects; plastic wrap, plastic cups, and most of our cars. This is not what a geologist means when he or she refers to rocks as being plastic. What he or she is referring to is a layer of solid rock that acts like a liquid. And what do liquids do that most solids don't? They flow. As a result of being able to flow, heat-driven convection currents, not unlike the convection currents in a pot of boiling water, rise from the bottom of the asthenosphere and impinge upon the bottom of the brittle lithosphere, spread laterally, and ap-

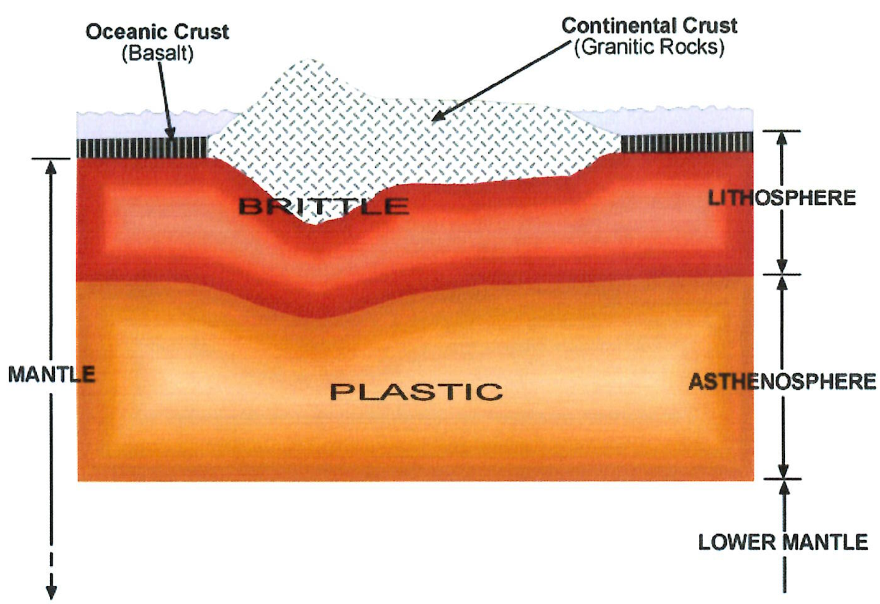

Figure 05. Drawing showing lithosphere and asthenosphere.

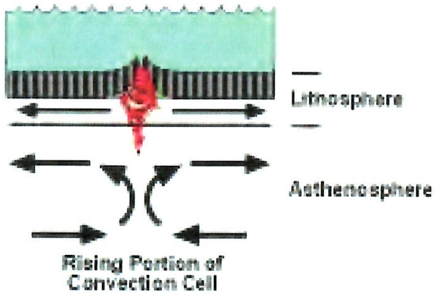

Figure 06. Breaking of lithosphere by convection currents.

ply forces that cause it to break into pieces called plates (Figure 06). Once the breaks form, basaltic magma rises to the surface along the breaks and forms a mountain range called an oceanic ridge (Figure 07). Every ocean has an oceanic ridge, all of which interconnect into a composite range approximately 40,000 miles long. Once the plates are formed, they are driven across the surface of Earth by several processes at a rate approximately equal to that at which your fingernails grow. One of the driving forces is the result of the lateral movement of asthenospheric rocks making up the upper portion of the convection moving away from the oceanic ridge called mantle drag (Figure 08). Another force involves the gravitational collapse of the rocks of the oceanic ridge that generate additional lateral forces away from the oceanic ridge called ridge push (Figure 09) and lastly, the eventual cooling of the convection cell results in the plate being dragged back down into the asthenosphere by slab pull where it is reheated and resumes its motion within the convection cell (Figure 10). Some of the plates such as the Pacific Plate consist primarily of oceanic crust and the underlying portion of the lithosphere while others such as the North American Plate consist of the combination of a mass of continental crust and oceanic crust riding on the underlying lithosphere. While the original description of the process involving the lateral movement of the continents was called "continental drift", we will see as our conversation continues that it is not the continents that are drifting, but rather the plate upon which the continent resides with the continent simply being carried along as a passive passenger.

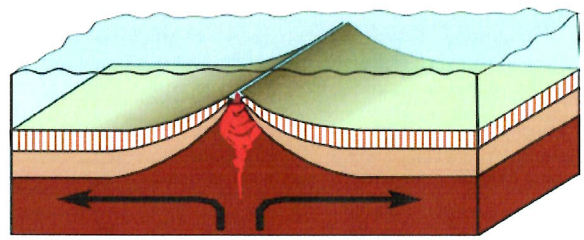

Figure 07. Drawing of oceanic ridge.

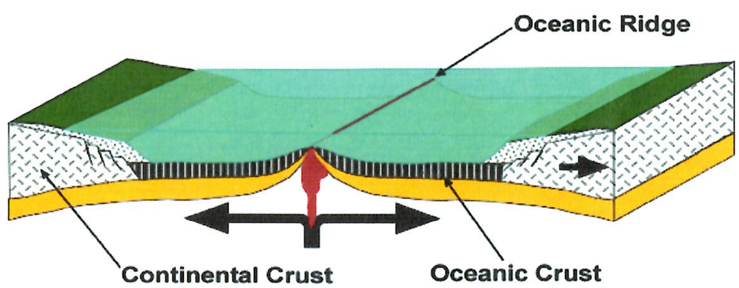

Figure 08. Drawing showing mantle drag.

Continental Drift: The idea of continental drift was a contentious one for centuries before the advent of plate tectonics. The concept of continental drift that involved the possibility that the continents have moved across Earth's surface was first proposed in 1596 by Abraham Ortelius and by a series of other scientists who had noted the similarity of the coastal outlines on opposite sides of the Atlantic Ocean; in particular between Africa and South America (Figure 11). It was, however, Alfred Wegener who, in 1912, first suggested that all of the present continents were once joined together into a single super-continent he called Pangea. He was the first to use the phrase "continental drift" to describe the fact that when Pangea broke up about 200M years ago, the individual pieces of the super-continent, now individual continents, drifted to their present positions (Figure 12). Wegener's problem was a problem faced by all the early "drifters", namely that he could not come up with a source of energy that could break super-continents into pieces and even if he had been able to find a source of energy, he could not picture a mechanism by which the energy was applied that resulted in the lateral movement

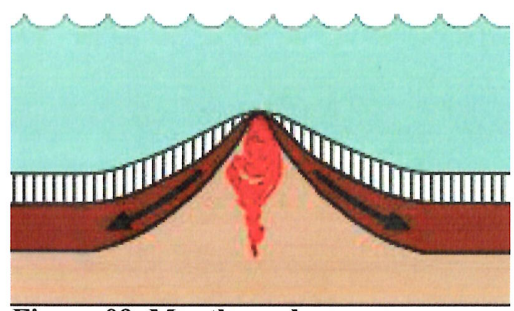

Figure 09. Mantle push.

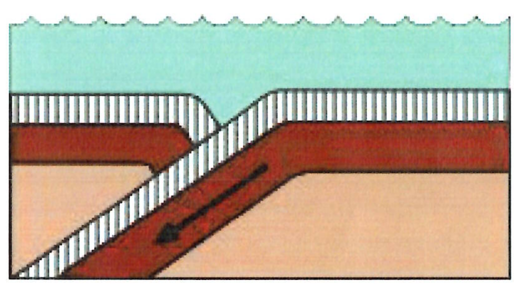

Figure 10. Drag of subducting plate.

of the continents. One of his suggestions, for example, was that the granitic crust plowed through the oceanic crust much like a ship plows through water. His problem was twofold. First, there was no evidence that the oceanic crust showed any degree of deformation from such a collision. Secondly, he could not propose a source of energy to drive the continental fragments forward. One must remember that at the time, the plastic asthenosphere and plate tectonics had not yet been identified. It was Arthur Holmes who, in 1944, suggested the presence of heat-driven convection cells within what we now know as the asthenosphere could, in fact, be the force that

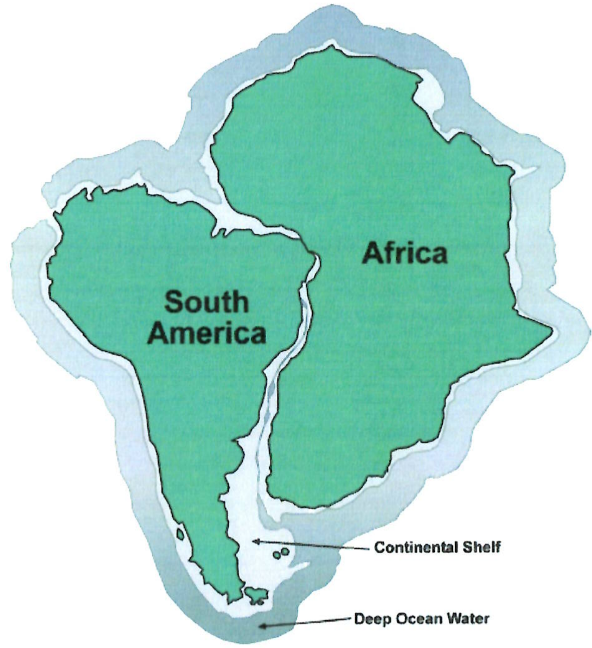

Figure 11. Map showing Atlantic margins of South America and Africa.

both broke the lithosphere into fragments and drove them laterally over Earth's surface. Unfortunately, his idea was rejected due the fact that at the time, the entire mantle was considered to be a brittle layer that could not support the plastic flow of convection cells. As we now understand the lateral movement of continents, it is not the continents that are being driven by heat-generated convection cells across the Earth's surface but rather the plates that are moving once the lithosphere was broken by the forces created by the underlying movement of the rocks within the convection cell. The continents are simply being carried on the plates as passive passengers much like the moving sidewalks transport passengers from one end of an airport hallway to the other.

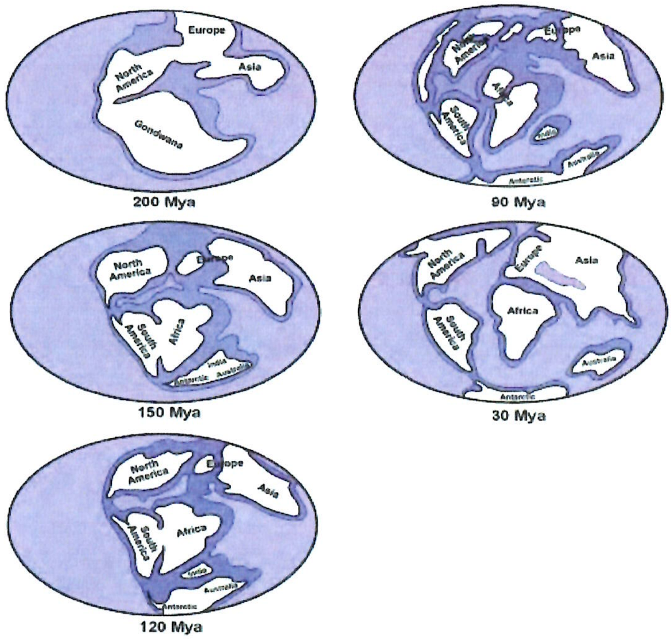

Figure 12. Breakup of Pangea.

Disparity of Crustal Ages: Before we leave the topic of Earth's crust, there is an interesting point to be made. Originally, the entire original crust supposedly formed during the same period of time about 4.5B years ago. While the oldest samples of continental crust recorded have ranged from 3.7B to 4.2B years, the oldest dated sample of oceanic crust is at most only about 250M years old. The obvious question is "what happened to the oceanic crust that existed before 250M years ago?" The answer lies in the movement of the plates. As the oceanic and continental plates move, they eventually collide along structures called zones of subduction (Figure 13). Because the basaltic oceanic plate is slightly denser than the granitic continental plate (3.1 vs. 2.9), when oceanic and continental plates collide, the oceanic plate is forced down beneath the continental plate where it undergoes melting and conversion back into mantle rock from whence it came. The answer to what happened to the original oceanic crust, is that the oceanic crust older than 250M years has long since been consumed at the zones of subduction and replaced with new oceanic crust being created at the oceanic ridges. But what about the continental crust? While some of the very old continental crust still exists, much of it has been removed from the continents by the combined efforts of weathering, mass wasting and erosion. At the same time, however, while older granitic crust is being removed, it is being replaced by new granitic rocks that are being created deep within the zones of subduction and brought to the surface during major mountain building episodes (Figure 14). Today, most of the granitic rocks that make up the continents are contained in the oldest portion of the continents called cratons where the rocks have remain unchanged for very long periods of time (Figure 15). If you've ever visited the Adirondack Mountains in upstate New York, you were standing on a portion of ancient granitic crust that is part of the craton called the Canadian Shield.

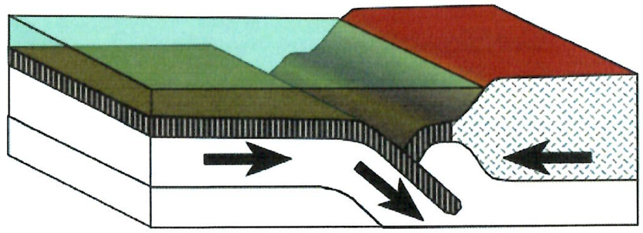

Figure 13. Drawing showing zone of subduction.

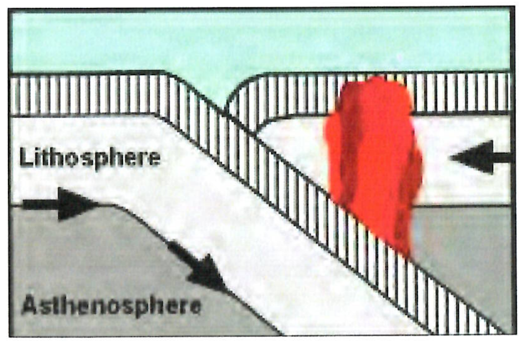

Figure 14. Drawing showing granitic magma in zone of subduction.

The Source of Water: Another question that needs to be answered is where did all the water come from that covers 70% of Earth's surface, flows down our rivers, forms glaciers, and is stored underground as groundwater? To answer that question, let us now go back to the time when the crust was forming as basaltic and granitic magmas were rising to the surface, cooling, and forming the oceanic and continental crusts. During this early time, volcanic activity was very extensive throughout the Earth's surface. As the basaltic magmas reach Earth's surface, enormous volumes of gases and ash are blown into the atmosphere to elevations of 30,000 to 40,000 feet. Of the gases re-

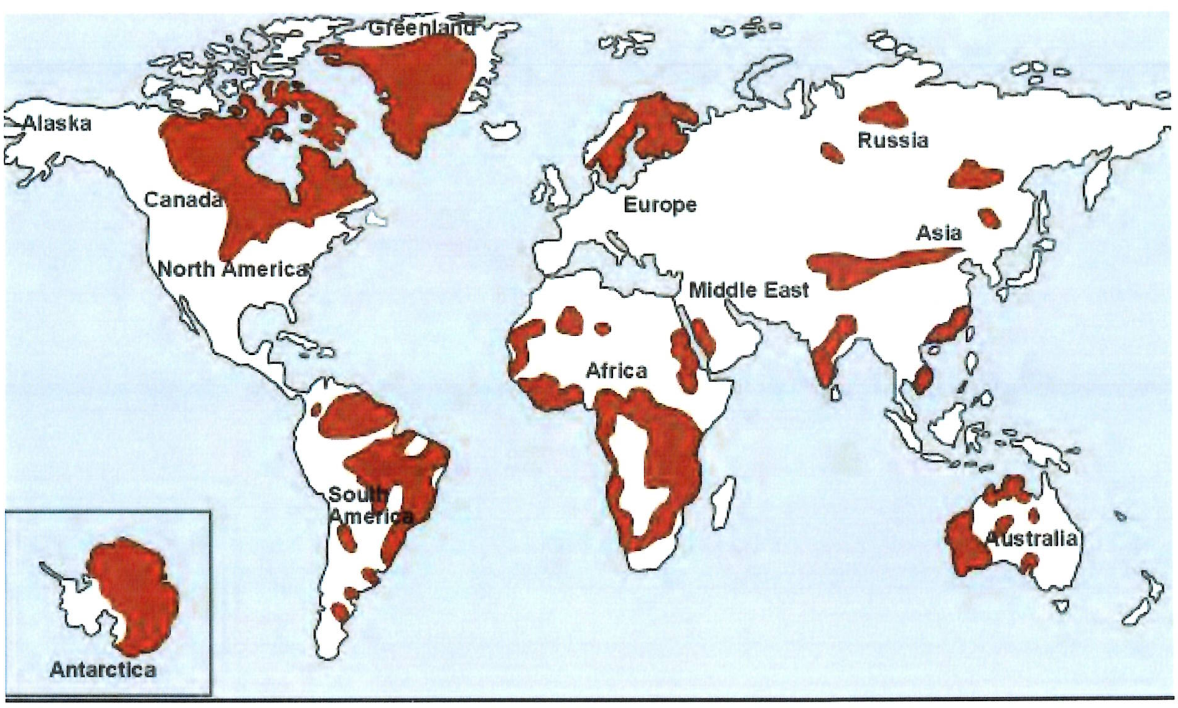

Figure 15. Map showing cratons.

leased during all volcanic eruptions, the major gas component is water vapor which eventually re-condenses into the liquid form. But how did the components of which water is made exist within molten rock? Certainly, it wasn't contained in gaseous or liquid form. You will remember that hydrogen was one of the major components of the cosmic dust that surrounded our evolving solar system. As the protoplanet was being created, hydrogen reacted with certain elements, in particular the alkaline earth metals such calcium to produce ionic hydrides:

$$Ca(s) + H_2(g) \rightarrow CaH_2(s)$$

Note that the hydrogen ion in hydrides is negatively charged as opposed to the positive charge it has in the acid ion (H1+) . As the molten rock rises to Earth's surface and cools, the hydrogen is liberated by a reaction with water which then reacts with oxygen to generate water which is released from the rising magma as it cools.

$$Ca\ H_2(s) + 2\ H_2O(I) \rightarrow 2H_2(g) + Ca(OH)_2(aq)$$
$$2H_2 + O_2 \rightarrow 2H_2O$$

Because Earth's surface at the time it was first being created was still far too hot to allow liquid water to exist on its surface, the water vapor rose into the atmosphere where it condensed into a thick cloud cover that enclosed the early Earth, blocking most of the radiant energy from the Sun. If it were not for the glow from the underlying molten lavas illuminating the bottoms of the overlying clouds, Earth would have been a dark and gloomy place. As time passed, perhaps a few billion years, the surface of Earth cooled, the basaltic and granitic lavas solidified, and the atmosphere began to cool to the point where the water vapor contained in the clouds began to condense to form rain and it began to rain for a very long time. The water ran off the granitic highs of the continents into the adjoining lower basaltic basins that eventually filled to form the oceans that now cover 70% of Earth's surface. Oceans may have formed as long ago as 4B years. Because of the volcanic activity that dominated these early times, the temperatures of these early oceans were near boiling. In addition, the waters were chemically reducing (anaerobic) with a pH of about 5.5 due to the presence of carbonic acid. Because granitic magmas were more viscous than basaltic magmas, they rose more slowly to the surface than the basaltic magmas. As a result, it is suggested that between 4.4B and 4.3B years ago, Earth was a water world with little continental crust. The continents would come later between 3B and 2.5B years ago when the highly viscous granitic magmas finally reached the surface and cooled to form the granitic rocks that make up the continental crust.

One question that needs to be answered is why does Earth have much more surface water than any other planet or moon in our Solar System? We already know that comets are a source of water; however, some geologists consider the amount of water provided by impacting comets does not provide the volume of water needed to create the oceans. What other sources could there be? Certainly the hydrogen contained in the molten magma was a possible source of water when released and reacted with oxygen. The condensation of the water being released during the melting and eruption of magmas would be another source. It is also believed that planetoids and asteroids contain water that would be released upon impacting Earth. For example, analyses of Moon rocks returned to Earth by Apollo 15 and 17 showed a deuterium ('Hl)-hydrogen (ICHI) ratio equal to that found in water on Earth indicating that water may have been present within Earth upon its creation as long as 4.4B years ago. Some of the water may also have been of bio-chemical origin. During the early 1930s, for example, it was discovered that sulfide-dependent purple sulfur bacteria could synthesize water as a byproduct of a photosynthetic pathway using hydrogen sulfide and carbon dioxide:

$$CO_2 + 2H_2S \rightarrow CH_2O + H_2O + 2S$$

Admittedly, few organisms use this method of photosynthesis today, making their contribution to the overall water mass negligible. Nonetheless, when all of these sources of water are combined, they could explain the large volume of water associated with Earth.

A Comparison of Earth and the Moon: Picture a time about 3B to 2.5B years ago. What did Earth's surface look like? First of all, the crust had completely formed. However, the land was barren; no plants or animals existed anywhere. If we were to pick a place that probably looks today much like what the early Earth did 3B years ago, we might pick the Moon. Why? Because Earth and Moon are closely related based on how the Moon is thought to have formed. The most widely accepted theory for the origin of the Moon is a collision of two proto planetary bodies during the early history of the Solar System, one about the present size of Earth and the other was an object the diameter of Mars called Theia. This "giant impact hypothesis" satisfies both the orbital conditions needed in order for a glancing blow to shear the Earth's crust off and place it in space where it could condense to form the Moon. At the same time, the collision with Theia would provide the Moon's with a small iron core while most of Theia's core was accreted into Earth's core. The result of such an impact was impressive. It is proposed by some scientists that the trillions of tons of Earth's crust that was vaporized and melted to create the mass of Moon rocks was originally torn from the surface of Earth, creating the basin now occupied by the Pacific Ocean.

Another question that arises has to do with the relative number of craters on Earth and the Moon. For example, beginning about 4.1B years ago and continuing until 3.8B years ago, both Earth and the Moon continued to be bombarded with untold numbers of meteoroids and comets, creating many craters. Over time, although the frequency of meteorite and comet impacts diminished, the impacts continue to this day. However, a question that must be answered is why are the craters we see on the Moon today so clear, sharp in outline, and numerous while those on Earth's surface are significantly fewer and much less apparent? As far as we know, both Earth and the Moon were being bombarded to the same extent during their early history. That being the case, where are Earth's craters? The fact of the matter is that they are there. With satellites orbiting Earth today, we are beginning to see the faint remains of many craters on Earth's surface, However, during the millions of years that have passed, the craters on Earth have undergone the processes of weathering and erosion to the point where they have been nearly erased. But why are the Moon's craters still present? The answer is simple. Unlike Earth, there is no water or atmosphere on the Moon to drive the processes of weathering and erosion. Therefore, while craters have remained on the surface of the Moon relatively unchanged for billions of years, the remains of craters on Earth have been reduced to a faint outline.

A Comparison of Earth and Mars: Rather than comparing Earth and the Moon, a better comparison might be between early Earth and Mars. Why? First of all there were distinct similarities between both planets during their early years. For example, there is no doubt that running water existed on the surfaces of both planets. The evidence for running water on Mars is the presence of stream channels, flood plain deposits and deltaic deposits where the streams flowed into larger bodies of water. The sediments that accumulate in such deposits are the source of sedimentary rocks such as sandstones and shales and, the iron oxides that make Mars the "red planet". While the Romans and Greeks named the planet after their gods of war, the Egyptians called it "the red one" and the Chinese named it "the fire star" after its color. Another similarity between Earth and Mars is both possess oceans; the main difference being that the Martian oceans only covered about 30% of the Martian surface while oceans cover 70% of Earth's surface.

Another important similarity that may have existed between the two planets is that both possess the only absolutely requirement for life as we know it namely, water. Assuming life once existed on Mars, it would have been restricted to the equatorial summers when temperatures reach 20°C (70°F), Life could not have existed in the winter polar caps where temperatures fall to -125°C (-195°F), Although definite evidence has not confirmed the presence of life, there seems to be quite a bit of circumstantial evidence to back the possibility that life as we know it once existing on Mars.

What happened to all the water that once existed on Mars? Some of it is still there. The ice caps at both poles consist of water ice covered with frozen carbon dioxide, a meter thick on the northern cap and eight meters thick on the southern cap. Although some frozen water might still exist deep within the Martian soil, the great volume of water disappeared along with the Martian atmosphere about 4B years ago, Today, the Martian atmosphere is essentially a vacuum, The highest atmospheric pressure on Mars today is equal to that which exists at 22 miles above Earth's surface with the mean surface pressure is only 0.6% that of Earth, What caused the disappearance of the Martian atmosphere? Several possibilities exist. The atmosphere could have undergone gradual removal by the impact of the solar wind, A report by NASA stated that most of the original atmosphere was removed between 4.2 to 3.7B years ago during solar storms when the planet's magnetic field was lost, Another possibility might have been a catastrophic collision with another celestial body that blew a significant portion of the atmosphere away.

The Appearance of Earth's Early Surface: You have all seen photos of the Martian surface, What does the land look like? Barren, desolate, and not appealing for life as we know it, Most of the surface is covered by fine-grained iron oxide (Fe_2O_3) resulting in Mars being referred to as the "red planet," During the early formation of Earth, it probably looked much the same; barren of life and desolate and covered with iron oxide resulting from the chemical weathering of the iron-rich basaltic of which most of Earth early crust was made, From the very beginning of Earth's formation, plates collided, creating mountains while the combined processes of weathering, mass wasting, and erosion erased them only to have them replaced by new mountains by another mountain building episode, It would be a very long time before any life would appear on the land, Although Earth's surface was barren of life, there were geologic processes underway from very early in Earth's history that constantly changed the appearance of Earth's surface, Water had already appeared as rain which, in turn reacted with carbon dioxide in Earth's atmosphere to form carbonic acid. Carbonic acid then began to attack the surface of Earth and chemically alter the exposed rocks. At the same time, water ice formed in places where temperatures were low enough. During cold winters, water entered cracks in surface rocks and caused them to disintegrate. At higher altitudes and further toward the poles, ice in the form of glaciers became an even more effective agent of physical weathering as it broke up rocks and ground them into finer pieces that they then transported into warmer climes where they were deposited. Once the Earth's surface became covered with the products of weathering, mass wasting driven by gravity transported the debris downslope where streams picked it up and carried it as part of the stream's bedload and suspended load, eventually to the ocean. All these processes continue to change the appearance of Earth's surface. Which brings up a very important point. A basic tenet of a new concept set forth in 1788 by the Scottish geologist, James Hutton, referred to as uniformitarianism stated that the same natural laws and processes that operate on Earth today, are most likely identical to those that operated in the past and that will continue to operate in the future. It was this concept that brought to an end a competing idea that Earth's surface was changed by catastrophic events; mountains that literally rose overnight, chasms such as the Grand Canyon that were created by Earth's surface being torn apart within hours. Now we know that mountains are created slowly by the collision of plates and disappear slowly by the combined effects of weathering, mass wasting, and erosion. The processes involved in uniformitarianism came into play the moment that Earth's crust was formed some 4B years ago and will continue until the end.

Geologic Time

The Cryptozoic Eon: (Refer to Figure 01) The Cryptozoic Eon (Gr. kryptos, hidden + zoon, life) is that period of time from Earth's origin up to the beginning of the Phanerozoic Eon (Gr. phaneros, visible + zoon, life) and the Cambrian Period, 570M years ago when abundant, recognizable fossils began to appear in the rocks. Because the Cryptozoic Eon precedes the Cambrian Period of the Phanerozoic Era, it is commonly referred to as the Precambrian. Based on the presence or absence of recognizable fossil remains, the Precambrian subdivides Earth's history into a very long pre-historic portion representing 90% of all geologic time with the Phanerozoic Eon representing a shorter historic portion. Note that we can make a similar comparison relative to human history with a very long pre-historic portion covering the time from the first appearance of Homo sapien about 2.5M years ago to the advent of the written word about 5,000 years ago.

The Cryptozoic Eon is subdivided into two eras; the Archean or Archaeozoic Era and the Proterozoic Era. The major event of the Archean Era was the creation of planet Earth from protoplanet Earth and the formation of Earth's crust. By the beginning of the Proterozoic Era, Earth's oceanic and continental crusts were complete and have remained constant in relative area ever since. Most geologists believe that Earth's crust was completed about 3 to 4 billion years ago. This is based on the fact that the oldest sample of granitic crust was dated at about 4.1B years old. Shortly after the creation of the crust, the process of plate tectonic was set into play, although little is known of the shapes and locations of the resultant continents and ocean basins.

The rocks of the two Precambrian eras are totally different. Because the Archean rocks had experienced intense deformation during the early creation of Earth, they are a mixture of highly deformed gneisses, granitic intrusions, greenstones, and meta-sediments. Because of the intense physical changes that the original rocks had undergone, little is known of the individual events that occurred during the first 2.5B years of Earth's history with absolutely no record remaining of the first 500M years of Earth's existence. The Proterozoic rocks, on the other hand, consist of well-sorted quartz sandstones containing ripple marks and cross bedding, conglomerates containing well-rounded and un-deformed quartz and chert pebbles and graywackes containing identifiable fragments of volcanic rocks. Perhaps the most interesting attribute of the Proterozoic rock sequence is the first appearance of limestones for which there are two requirements: 1) warm water, and 2) near-absence of clastic sediments in the water. The requirement of warm water has to do with the chemistry of carbonic acid and the fact that calcite, $CaC0_3$, Is more soluble in cold water than In warm. The reaction that results In the formation of limestones begins with the reaction between carbon dioxide and water to create carbonic acid, H_2CO_3:

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^{1+} + HCO_3^{1-}$$

Molecular carbonic acid then dissociates into the acid ion, Hit and the bicarbonate ion, HCO31-:

$$H_2CO_3 \leftrightarrow H^{1+} + HCO_3^{1-}$$

The double-ended arrow indicates that the reaction can go in either reaction, in this case depending on the temperature. Low temperatures promote the reaction of water and carbon dioxide to form dissociated carbonic acid whi1e warm water promotes the opposite reaction. The reaction of calcite, CaCO, and dissociated carbonic acid is as follows:

$$CaCO_3 + H^{1+} + HCO_3^{1-} \leftrightarrow Ca^{2+} + 2HCO_3^{1-}$$

In cold water, the reaction proceeds to the right resulting in the dissolution of calcite. In warm water, on the other hand, the reaction proceeds to the left forming un-dissociated carbonic acid that breaks down into water and carbon dioxide that returns to the atmosphere while calcite precipitates from solution to provide the carbonate material from which the shells of marine animals form. In summary, calcite dissolves in cold water and precipitates in warm water. The need for clear water is to prevent suspended sediments from choking the carbonate-producing animals.

Precambrian Tectonics: At least two supercontinents existed during the Precambrian. The first called Columbia formed about 1.8B years ago of which we know little. About lB years ago, a major orogenic event that is critical to our understanding of how North American geology took place. Called the Grenville Orogeny, it created a super-continent called Rodinia which existed until about 700M ago years when it began to breakup, forming a number of continents surrounding a new ocean called the Iapetus (the predecessor of the Atlantic) (Figure 16). One of the larger continents created during the breakup was Laurentia, consisting of what is now North America and Greenland. Three other fairly large continents were Baltica, extending from Europe eastward to the present Ural Mountains of western Asia, Gondwana, consisting of all of the continents presently located in the southern hemisphere, and Asia-Siberia. In addition, there were two smaller continental masses, the Piedmont Micro-Continents and Avalonia. Our understanding of these continents and the events that created them plus detailed studies of the geology of the present continents has provided us with the evidence we have needed to fit this complex puzzle together.

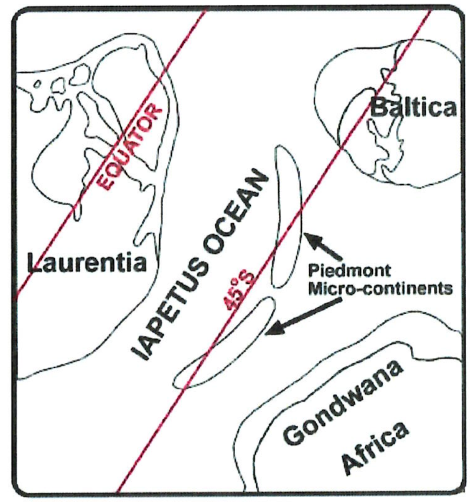

Figure 16. Breakup of Rodinia.